Fast and Fine Tracking Control System Using Coarse/Fine Compound Actuation

SangJoo Kwon — *Ph.D. Student*
Wan Kyun Chung — *Professor*
Youngil Youm — *Professor*
Department of Mechanical Engineering
Pohang University of Science & Technology(POSTECH), Pohang, KOREA
Tel: +82-54-279-2844; Fax: +82-54-279-5899; E-mail: ksj@postech.ac.kr, wkchung@postech.ac.kr

Abstract

A dual-stage positioner for fast and fine robotic manipulations is presented. By adopting the merits of both coarse and fine actuator, a desirable system having the capacity of large workspace with high resolution of motion is enabled. We have constructed an ultra precision XY positioner with dual-stage mechanism where the PZT driven fine stage is mounted on the motor driven XY positioner and applied it to fine tracking controls and micro-tele operations as a slave manipulator. We describe essential merits of the compound actuation mechanism and some control strategies to successfully utilize it with proper servo system design. Through experimental results, the effectiveness of the coarse/fine manipulation by the dual-stage positioner will be shown.

1 Introduction

Two major source of hindering control performance in systems with conventional actuators(hereafter "coarse actuators") such as electrical motors or hydraulic actuators may be the nonlinear friction in low speed motion and the resonance mode in high frequency motion area. On the other hand, "fine actuators" such as piezoelectric actuators(PZT) are free of friction problem and so much higher resolution of motion is possible but it is limited in motion range, at most, to several hundreds of micron. As a trial to overcome the limitations of conventional actuators, several compound actuation systems with dual-stage construction were investigated for different applications [1–5]. The purpose of compound actuation is to achieve the capacity of both coarse and fine actuators in a system by adopting the merits of them. In compound actuation systems, both coarse and fine actuator are complementary to each other, *i.e.*, the coarse actuator offers large workspace and actuation power while the fine actuator enables high resolution of motion and so defects of a actuator is compensated by the merit of other actuator. There were lots of studies where the concept of dual-stage compound actuation is applied. For example, we can find works on macro/micro robot manipulators [6–8] and dual-stage XY positioning tables [4,5]. However, these days, the research on the dual-stage servo seems to be most active in hard disk drives(HDD) [1–3], where the 2nd actuator fabricated using micro machining technology enables high speed track following.

In this paper, based on our former report [5], we primary show experimental results applying the dual-stage positioner we have constructed to micro-tele operations as well as fine tracking control. Above all, we describe the system configuration in section 2. Control strategies which are requisite for successful dual-stage manipulations are given in section 3 with some mechanical considerations in compound actuation mechanism. A dual servo algorithm is briefly explained in section 4. Section 5 demonstrate experimental results including micro-tele operation. Finally, section 6 concludes this paper.

2 System Configuration

For fine tracking control applications or microscopic manipulation in micro-tele operating systems, we have constructed a dual-stage positioner where the fine stage is mounted on the coarse positioner as shown in Fig. 1, where the below coarse positioner offers a large work area of 200×100 *mm* in (x_1, y_1) coordinate plane and the upper fine positioner enables nano level resolution of motion with travel range of 100×100 μm in (x_2, y_2) plane. While, position sensors of coarse and fine stage are encoder and capacitive gap sensor, respectively. The absolute accuracy of each positioner in closed-loop motion is about 20 μm in coarse positioner and at least sub-micron in fine positioner. As a result, by the cooperative manipulation of both postioning stages, a fast and fine manipulation with large workspace is possible. Figure 2 denotes the system configuration of the dual-stage positioner in closed-loop, where coordinates of end-point of the dual-stage is $(x = x_1 + x_2, y = y_1 + y_2)$. So, there exists a redundancy of motion for each direction. While, the fine positioner is driven by piezoelectric actuator(PZT) with flexure hinge mechanism and the coarse positioner is driven by BLDC motors with ball-screw mechanism. In the dual-stage positioner, the fine stage has much faster dynamics than the coarse stage and so its high frequency redundant motion (x_2, y_2) make it possible to compensate considerable tracking errors which may occur in the coarse positioner.

Considering the mathematical models of the dual-stage positioner in Fig. 1, the ball-screw driven positioner can be simply described as a mass-damper system: $H_n \ddot{z}_1 + B_n \dot{z}_1 = u_1(t)$, where the coordinate, $z_1 = (x_1, y_1)$, the control input, $u_1(t)$ corresponds to bipolar voltage input with $-5 \sim 5$ *Volt*, and the nominal parameters, inertia and viscous damping coefficient, are identified as $H_n[Volt/(m/s^2)] = (0.2020,\ 0.1665)$, $B_n[Volt/(m/s)] = (2.25,\ 1.35)$ for (x_1, y_1) axis, respectively. On the other hand, the PZT driven fine positioner accepts unipolar input with $0 \sim 10$ *Volt* and its motion is produced by elastic deformation of the flexure hinge and so there exists no friction due to hard contact. So, the mass-spring model such as $m\ddot{z}_2 + k\dot{z}_2 = u_2(t)$ is adequate for the fine stage, where the driving force($u(t)$) has the relationship to unipolar voltage input($V(t)$) as $u_2(t) = K\frac{dV(t)}{dt}$, i.e., the generated force in the PZT is proportional to the rate of change of input